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by

C. H. M. van Bavel and L. A. Forrest

Soil and Water Conservation Research Branch
Agricultural Research Service

in cooperation with the

Soils Department
North Carolina Agricultural Experiment Station

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Soil temperature measurement is becoming a necessity in certain agricultural operations. The two best examples are the use of liquid ammonia for nitrogen fertilization and the use of certain volatile organics for pest control, particularly as nematocides. It is important to have a practical thermometer which is sufficiently precise.

Dial thermometers have advantages for measuring soil temperature. They are easily installed and easily read, without undue chance for errors. Sturdy and weatherproof in construction, they are usually much cheaper than mercurial or electrical thermometers adapted for use in soil.

The question arises, of course, whether a dial thermometer has sufficient precision and, in particular, one wonders about the possible effect of heat conduction through the stem.

This report deals with the evaluation of a simple dial thermometer 1/ used at two soil depths. The standard was considered to be the data from a resistance thermometer (Thermistor) 2/ placed at identical depths in the soil.

Methods

The Weston Dial thermometer is an all metal instrument employing the bimetal principle of temperature indication. The particular instru-

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1/ Manufactured by Weston Electrical Instrument Company, Newark 5, New Jersey. This information does not constitute endorsement of the instrument nor denies the superiority of other makes.

2/ Manufactured by the Western Electric Company, 30 Church Street, New York, N. Y. See footnote 1.

ment used was designated by the manufacturer as model 2261. It has a dial type scale with a needle-like pointer. The stem is a stainless steel case 0.142 inches in diameter and 8 inches long. The temperature sensitive element, a strip of bi-metal wound into a helix, is mounted in the lower two inches of the hollow stem. The pointer is connected to the sensitive element by means of a small metal rod. The dial scale is 1 3/4 inches in diameter and is fastened at right angles to one end of the stem which facilitates reading temperatures without disturbing the thermometer. The dial reads in °F, with a division to each degree. An idea of the accuracy of the four dial thermometers used is obtained from the following table, data for which were obtained in a water bath.

Mercury	Dial 1	Dial 2	Dial 3	Dial 4
41.0	38.5	38.0	39.5	39.5
50.0	49.5	48.5	49.5	49.5
64.0	62.0	62.0	63.0	63.0
74.0	72.5	72.5	73.5	73.0
85.0	83.5	83.0	84.0	84.0
94.1	92.0	92.0	93.0	92.5

The thermistor used is designated by the manufacturer as model No. 7A disc type thermistor and is the same unit used in the Colman fiberglass soil-moisture element. It is a pellet of metal oxide, silver coated on its opposing sides, 0.2 inches in diameter and 0.037 inches thick. The manufacturer's rated resistance is 1,000 ohms, plus or minus 10 percent at 25 degrees centigrade. The resistance of the pellet is sensitive to changes in temperature. Consequently, it can be used to determine temperature.

Each of the two types of thermometers was installed, in duplicate, at 4- and 8- inch depths in Cecil clay loam soil, covered with a Bermuda grass sod. They were installed in a rectangular block such that there were four of one type in line, spaced about one foot apart, with the first and third thermometer being at the 4-inch depth and the second and fourth at the 8- inch depth. This pattern was repeated for the second type with the line of thermometers placed about one foot from the first type and parallel to them. This installation resulted in the two types and depths being equidistant from each other.

The dial type thermometers were installed by forcing the stem into the ground to the desired depth. Soil temperatures were read directly in degrees Fahrenheit from the dial scale without disturbing the thermometers. A point 1 inch from the bottom of the stem was taken as the reference for depth. The 8- inch thermometer was therefore sunken into the surface by 1 inch.

The thermistors were installed by removing a small core of soil to the desired depth and placing the thermistor pellet, with the lead wires attached, on the bottom of the hole. The soil was replaced and firmed around the pellets and lead wires. The lead wires were brought out and fastened to a platform on top of a post 3 feet tall to facilitate reading the ohmmeter used to measure the resistance of the thermistor. Soil temperatures were determined from a calibration curve previously prepared in the laboratory with a standard mercury thermometer for each thermistor used. The calibration was carried out in a water bath.

Results

The thermometers were installed on December 1, 1954 and soil temperatures were recorded each morning during four different time periods between December 15, 1954 and July 18, 1955, see Table 1. During the last two time periods, temperatures were recorded two or more times on each of several days. The time periods for recording temperatures were selected so that one would expect increasing temperatures with successive time periods without too much overlapping. The first period of measurement was from December 15, 1954 to January 3, 1955, and included 19 days on which temperatures were recorded. During this period, soil temperatures ranged from 33 to 51 degrees. The second period of measurement was from March 11 to April 6. This period included 22 days of record with temperatures ranging from 45 to 58 degrees. The third period of record ran from April 25 to May 10 and included a total of 15 measurements in 7 days. The temperatures ranged from 63 to 78 degrees. The fourth and final period of measurement was from July 5 to July 18. Fifteen observations were recorded in 9 days with temperatures ranging from 76 to 92 degrees. Thus, each successive period covered a higher temperature range than the previous period with a minimum of overlapping.

An analysis of the variance of the data was made. The main point of interest was the comparison of the two types of thermometers and its interaction with the other factors such as period, time of day, and depth of installation. The analysis is presented in Table 2.

A significant deviation was found of the dial thermometers from the thermistors, which are here considered as standards. The actual difference is quite small, however, the average temperature for the dial thermometers being 59.0 °F as compared to 60.2 °F for the standard.

Furthermore, variable results were obtained in the four periods studied as indicated in following table.

	Dial	Resistor
Period 1	40.8 °F	45.4 °F
" 2	52.2 °F	52.5 °F
" 3	69.0 °F	68.7 °F
" 4	82.0 °F	81.7 °F

Since a least significant difference between two period means is about 0.7 °F, it is evident that a real discrepancy existed only during the first period. It is felt that this reflects the initial disturbance of the soil which was entailed by the installation of the thermistors.

The discrepancy between the two types of measurement was larger at the 4-inch depth (1.4°F) than at the 8-inch depth (1.0°F). In studying the analysis of variance among Dials and Resistors (items 9, 10, 11, and 12 of Table 2) it would appear that there is good agreement between replicate installations except the two resistor thermometers at 8 inches. The analysis of variance among Dials and Resistors x Periods (items 13, 14, and 15) however, show this is false. The significant effects noted here are explained by the data in Table 3. It may be noted in this table that the discrepancies between replicate installations vary with the period and apparently this effect is real. It may be caused by surface conditions, inequalities in moisture content of the soil or other minor site differences. It should be emphasized that all these differences are of little practical significance.

The precision of measurement can be estimated from the analysis among Dial and Resistor x Observations (items 20, 21, 22, and 23 of Table 2). A standard error is obtained of about 0.5°F for the dial thermometers and of about 0.6°F for the resistance thermometer. These figures indicate a sampling error owing to site.

The dial thermometer can be read to the nearest degree and the resistance thermometer to the nearest 0.3°F.

It appears, therefore, that the instrumental error is as large or larger than the systematic deviation owing to site, or to a particular choice of instrument. In other words, within the limits of its precision, the dial thermometer appear to measure the true soil temperature at 4 inches and at 8 inches depth and, a fortiori, at greater depths.

The results have been graphically presented in Figures 1 through 4. Figures 1 and 2 demonstrate the equivalence of the two types of measurement, with exception of the lower values which are those found in the first period. The line drawn is a 45° line made for comparison.

The data obtained on days when more than one measurement was made are shown in Figures 3 and 4. It is shown here that the time of the day, as far as studied, has no influence on the discrepancy between methods. A 45° line is again shown in these two illustrations.

Conclusions

Data obtained over a nine month period show that soil temperatures measured with a commercial dial thermometer are accurate to better than 1°F, which is about the precision with which such thermometers can be read.

Systematic influences on accuracy were found, such as depth, time of year, and site but these effects were all minor.

The experience showed that dial thermometers are very easy to install and to read and that they seemed to stand up well under outdoor exposure.

Use of dial thermometers for experimental purposes, as well as for agricultural and engineering applications, seems well justified, also on the basis of the relatively low cost. It should be pointed out that this type thermometer can be had with maximum and minimum indicators, as well as with any length of stem.

Table 1. Soil temperatures measured with a bi-metal dial-type thermometer compared to the temperatures measured with a thermistor.

		Soil Temperatures							
		4-inch depth				8-inch depth			
		Dial Therm.		Thermistor		Dial Therm.		Thermistor	
		No.1	No.3	No.1	No.11	No.2	No.4	No.4	No.14
Date	Time	°F	°F	°F	°F	°F	°F	°F	°F
12-15-54	9:00 A.M.	39	39	45	44	40	40	46	45
16	"	37	37	43	42	39	38	44	44
17	"	37	37	42	41	39	38	43	42
18	"	44	45	48	46	43	44	48	46
20	"	38	38	44	43	40	40	45	45
21	"	35	35	44	43	38	37	45	44
22	"	34	34	41	41	36	35	43	42
23	"	33	33	41	41	35	35	43	41
24	"	35	35	42	42	36	36	43	42
25	"	35	35	42	42	37	37	44	43
26	"	35	35	42	42	37	36	44	43
27	"	38	38	44	44	39	39	45	44
28	"	42	42	46	46	42	42	47	45
29	"	49	49	50	50	48	48	50	49
30	"	51	51	51	51	51	51	51	50
31	"	45	44	48	49	46	46	49	48
1-1-55	"	46	46	49	48	47	47	49	48
2	"	48	48	50	49	48	48	50	49
3	"	45	45	48	47	46	46	49	48
3-11-55	12:00 N	55	56	56	57	54	54	53	53
14	9:00 A.M.	57	56	56	56	57	57	57	57
15	"	54	54	54	52	55	54	57	55
16	"	56	55	56	56	56	55	55	55
17	"	53	53	53	52	54	54	54	54
18	"	55	55	55	55	55	55	55	55
19	"	52	52	52	50	53	52	53	51
21	"	52	52	52	52	52	52	52	51
22	"	58	58	58	58	58	58	59	56
23	"	50	49	50	49	52	50	52	51
24	"	50	49	50	49	51	52	51	51
25	"	52	52	52	51	53	52	52	52
26	"	54	54	54	54	54	54	54	53
28	"	45	44	48	47	47	45	49	49
29	"	46	45	48	48	47	46	49	49
30	"	45	45	48	48	47	46	49	49
31	"	47	47	49	48	48	48	50	49
4-1-55	"	49	49	50	49	50	50	52	50
2	"	54	54	54	54	53	53	53	52
4	"	54	53	53	53	55	54	53	54
5	"	53	53	53	53	55	54	53	54
6	"	56	55	55	55	55	55	55	56

Table 1. Continued

		Soil Temperatures							
		4-inch depth				8-inch depth			
		Dial Therm.		Thermistor		Dial Therm.		Thermistor	
		No.1	No.3	No.1	No.11	No.2	No.4	No.4	No.14
Date	Time	°F	°F	°F	°F	°F	°F	°F	°F
4-25-55	10:00 A.M.	69	69	69	69	68	68	68	67
25	1:00 P.M.	70	70	70	70	69	70	68	69
25	5:00 P.M.	70	70	69	69	69	69	68	69
26	8:00 A.M.	63	63	63	63	65	64	64	64
26	10:00 A.M.	65	65	64	64	65	64	64	64
26	12:00 N.	67	68	67	69	66	66	64	64
5-5-55	8:00 A.M.	67	67	67	68	68	68	68	67
5	10:00 A.M.	69	70	69	69	68	68	68	67
5	1:00 P.M.	74	75	74	76	70	71	70	69
5	3:00 P.M.	76	77	76	78	72	74	71	74
5	5:00 P.M.	77	77	77	78	73	75	73	72
6	9:00 A.M.	68	69	68	69	69	69	68	69
7	"	67	67	67	67	68	68	66	67
9	"	68	68	68	69	69	69	68	69
10	"	68	69	69	69	69	69	68	69
7-5-55	"	80	81	80	80	80	80	79	79
5	1:00 P.M.	86	87	87	88	82	84	83	81
6	9:00 A.M.	80	80	80	80	80	81	80	80
6	1:00 P.M.	86	88	87	85	83	84	83	82
7	9:00 A.M.	81	81	81	81	81	81	81	80
7	1:00 P.M.	88	89	87	90	88	85	83	82
8	9:00 A.M.	80	80	81	80	79	79	80	79
9	"	79	79	78	78	79	79	79	78
11	"	79	79	79	80	79	79	79	79
11	1:00 P.M.	84	85	85	86	81	82	81	80
12	9:00 A.M.	78	78	78	77	78	78	79	78
14	"	76	76	72	75	76	76	76	76
18	"	82	83	82	83	82	82	83	83
18	1:00 P.M.	87	89	87	89	84	85	84	83
18	4:00 P.M.	90	91	91	92	86	88	88	86

Table 2. Analysis of variance of soil temperatures measured at two depths with a pair of dial thermometers and a pair of resistance thermometers during four time periods.

Item	Source	DoF	SS	MS	F
(1)	Pe(riods)	3	120,422.875	40,140.958	
(2)	De(ptns)	1	5.922	5.922	
(3)	Ob(servations within periods)	67	6,902.914	103.029	
(4)	De x Pe	3	149.328	49.776	
(5)	De x Ob	67	292.250	4.362	
(6)	D(ial vs.) R(esistor)	1	191.725	191.725	48.8^{**}
(7)	DR x Pe	3	602.843	200.948	49.1^{**}
(8)	DR x De	1	5.522	5.522	11.4^{**}
	Among Dial and Resistor	4			
(9)	D4"	1	.570	.570	3.88 NS
(10)	D8"	1	.254	.254	0.73 NS
(11)	R4"	1	.000	.000	0.00 NS
(12)	R8"	1	10.711	10.711	26.71^{**}
	Among Dial and Res x Pe	12			
(13)	D4" x Pe	3	5.077	1.692	11.51^{**}
(14)	D8" x Pe	3	4.283	1.428	4.08^{**}
(15)	R4" x Pe	3	10.437	3.479	8.17^{**}
(16)	R8" x Pe	3	7.898	2.633	6.57^{**}
(17)	DR x Pe x De	3	2.908	.969	1.99 NS
(18)	DR x Ob	67	273.932	4.089	
(19)	DR x De x Ob	67	32.570	.486	
	Among Dial and Res x Ob	268			
(20)	D4" x Ob	67	9.853	.147	
(21)	D8" x Ob	67	23.463	.350	
(22)	R4" x Ob	67	28.563	.426	
(23)	R8" x Ob	67	26.891	.401	
	Total	567	129,010.789		

In making the F-test items (6) and (7) are compared with item (18), item (8) with item (19), items (9), (10), (11), and (12) with items (20), (21), (22), and (23) respectively, and items (13), (14), (15), and (16) also with items (20), (21), (22), and (23) respectively.

Table 3. Average soil temperatures by thermometer, depth, and period.

	4 inches				8 inches			
	Dial 1	Dial 3	Res. 1	Res. 11	Dial 2	Dial 4	Res. 4	Res. 14
Period 1	40.3	40.3	45.3	44.8	41.4	41.2	46.2	45.1
Period 2	52.1	51.8	52.5	52.1	52.8	52.3	53.0	52.5
Period 3	69.2	69.6	69.1	69.8	68.5	68.8	67.7	68.0
Period 4	82.4	83.1	82.3	82.9	81.2	81.5	81.2	80.4

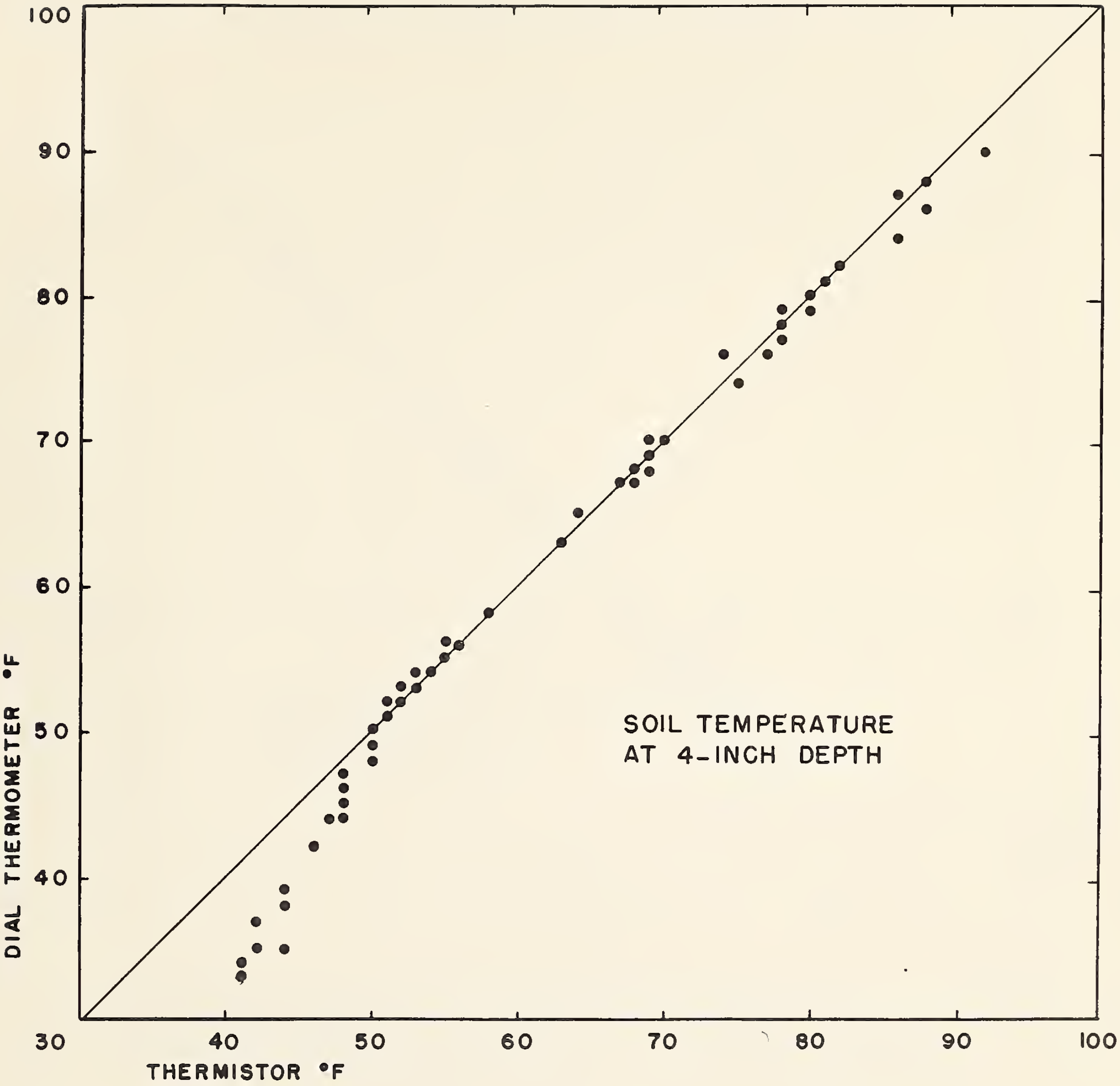

Figure 1. Comparison between the dial thermometer and thermistor for soil temperatures at 4-inch depth. Average of two values for all points.

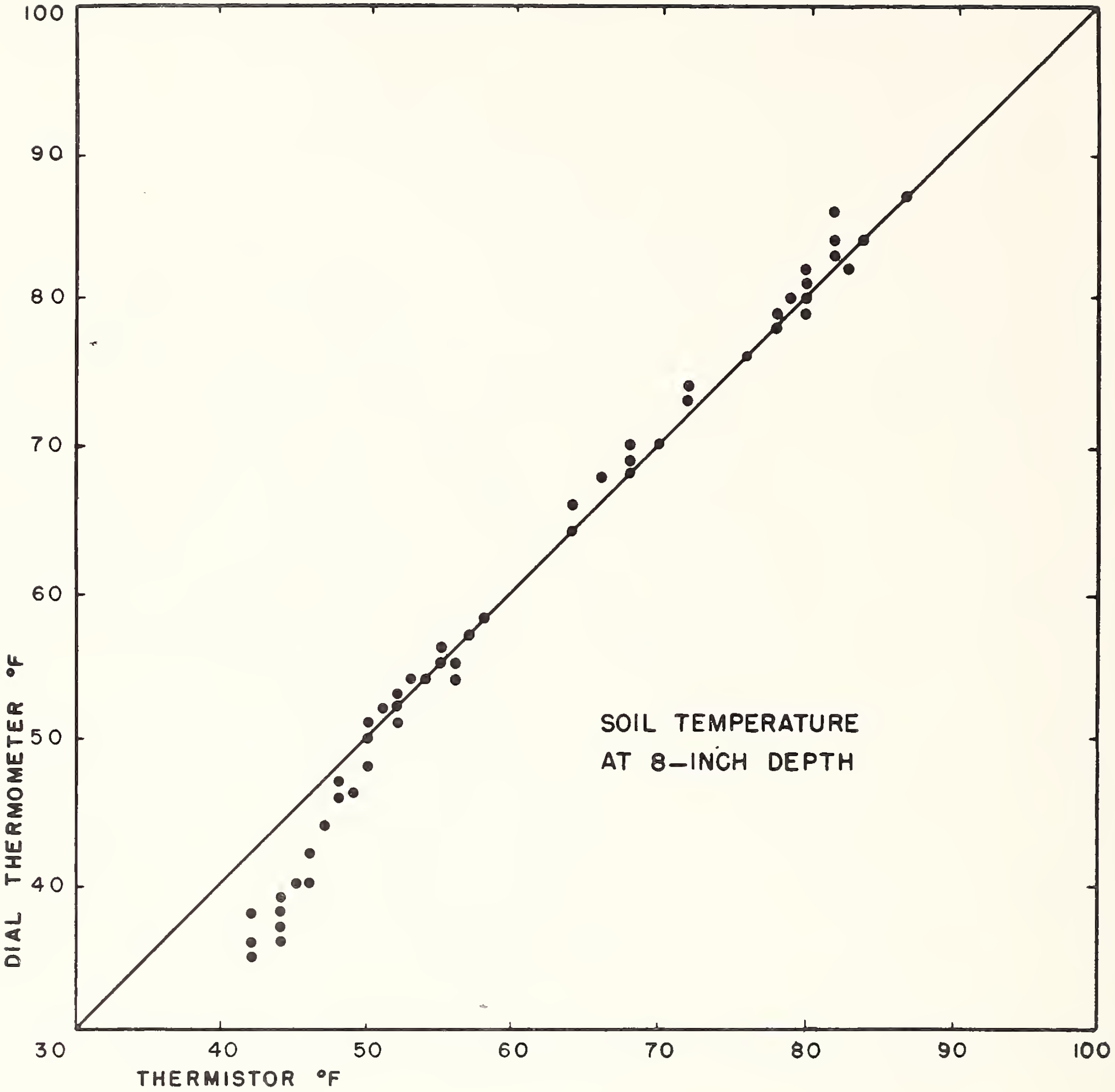

Figure 2. Comparison between the dial thermometer and thermistor for soil temperatures at 8-inch depth. Average of two values for all points.

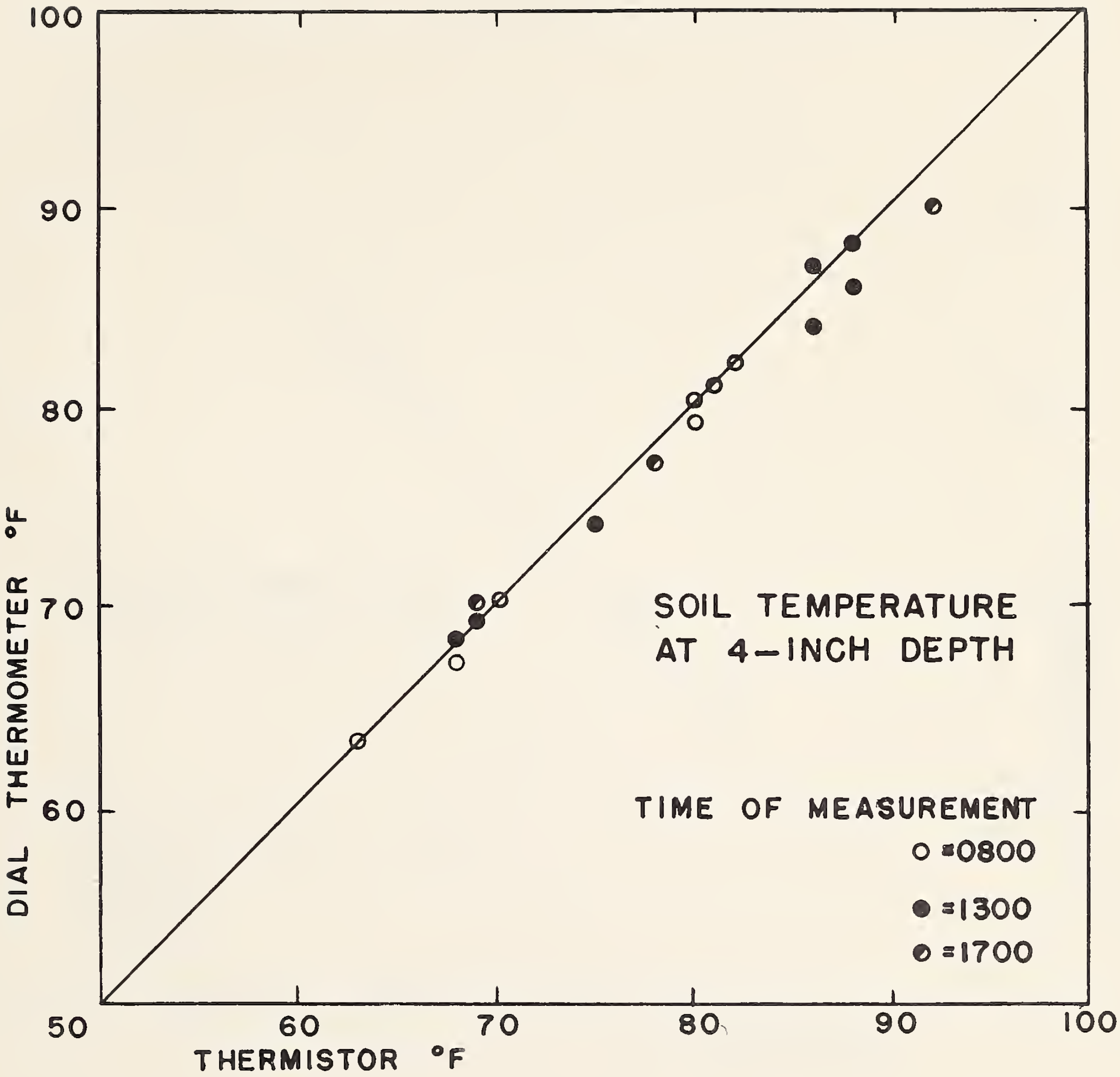

Figure 3. Soil temperatures at different times of the day as measured by the dial thermometer and thermistor at 4-inch depth. Average of two values per point.

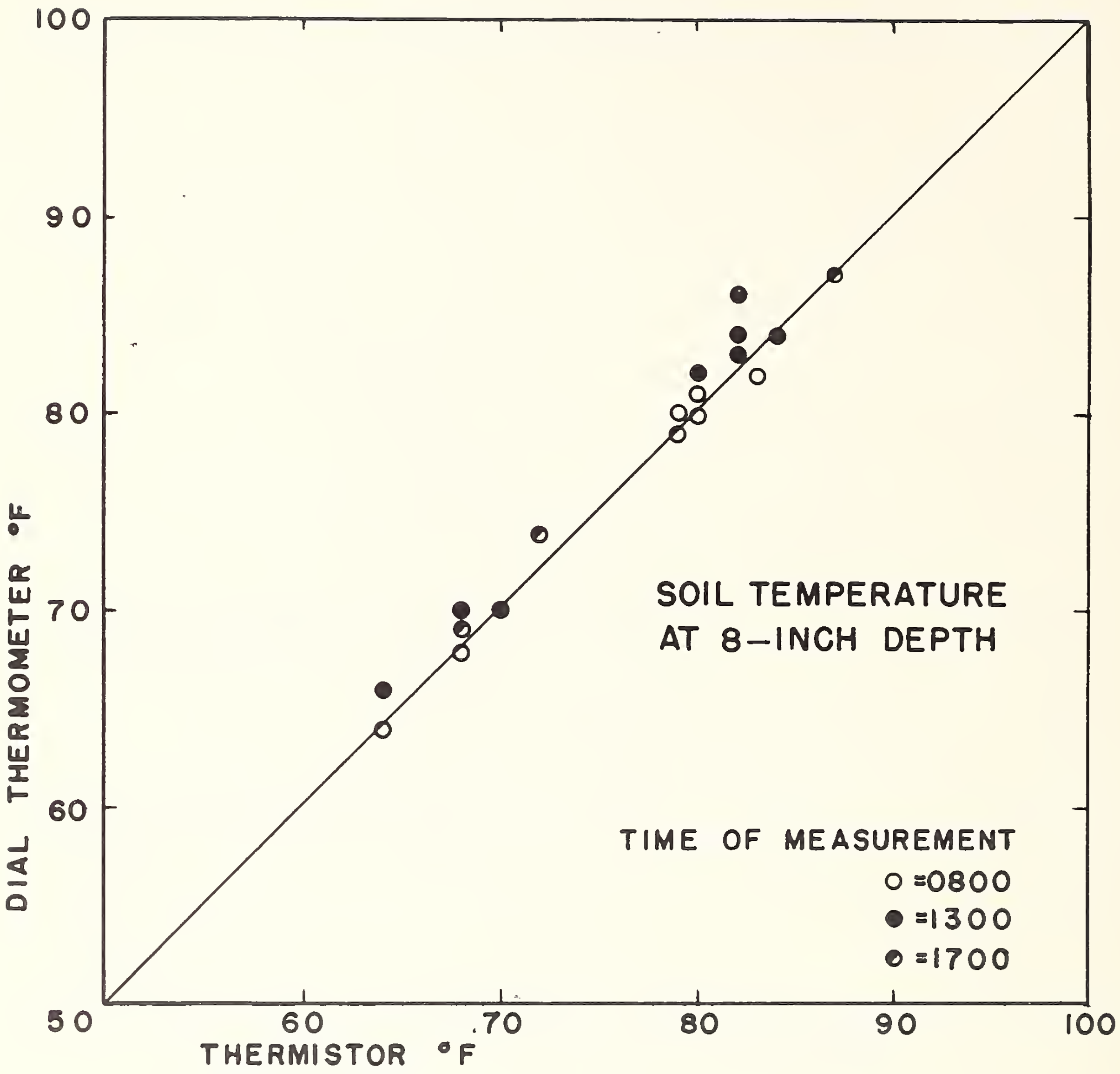

Figure 4. Soil temperatures at different times of the day as measured by the dial thermometer and thermistor at 8-inch depth. Average of two values per point.